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Updated Vault Toilet Concepts

FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE
EQUIPMENT DEVELOPMENT CENTER
SAN DIMAS, CALIFORNIA

EQUIPMENT DEVELOPMENT AND TEST REPORT 2300-13

UPDATED VAULT TOILET CONCEPTS

by

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A combined report covering four ED&T projects:

- 1435—Environmental Technical Services
  - 2362—Toilet Vaults
    - 2440—Integrated Field Evaluation of Vault Toilet Systems
      - 2619—Vault Toilet Venting Systems Redesign

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FOREWORD

Vault toilets are still very much with us and will be until some new technology obviates their need. Over the past 5 years the Environmental Staff Engineer at the San Dimas Equipment Development Center (SDEDC) has been conducting vault toilet improvement projects. This document highlights the more challenging design, construction, and maintenance problems that were encountered and presents information and advice for the:

- *Individual who designs the toilets,*
- *Manager who administers recreation sites, and*
- *Maintenance supervisor who oversees the servicing of the toilet vaults and buildings.*

Information on below-ground vault design and maintenance is in a previous publication, "Vault Toilets . . . design and maintenance considerations," February 1976; available from SDEDC.

INTRODUCTION

Vault toilets have been a part of the outdoor recreation environment for a very long time. Presently, approximately 40,000 vault toilets in over 26,000 vault toilet buildings are under Forest Service jurisdiction, with more being constructed each year. As administrators of public recreation sites in the National Forest System, the Forest Service strives to provide toilet facilities that are as economical, practical, visually appealing, and odor-free as possible.

This document contains information and recommendations on the design, construction, and maintenance of the building interior; the new design criteria for building and vault venting systems; chemical and biological additives for vault odor control; materials for use in constructing the below-ground vault; and some inventory lists depicting the diversity of vault contents.

INTERIOR BUILDING CONSTRUCTION

Materials specified for vault toilet building interiors should be non-porous, durable, easily maintained, and aesthetically appealing. Items specified for placement within the building should be practical, convenient, and vandal-proof.

Entrance Doors

Wherever possible toilet buildings should have steel doors and door frames with a heavy-duty, rust-resistant finish. They provide a tight fit and are easier to maintain than wooden ones, which are carvable and can warp. Further, some of the more flimsy wooden doors have invited removal—either for firewood or the fun of it. For safety and cleaning ease, all doors should be installed to open outward. Hydraulic door closures help prevent door slamming and wind damage.

Floor Surfaces

For public safety, floors in vault toilet buildings should have nonskid surfaces. All cracks and crevices should be carefully filled in, and the surface sealed. All corners and wall/floor baselines should be rounded. This provides easier cleanup and prevents both the absorption of odorous material and the formation of unsightly stains.

Various polymeric coatings for sealing concrete floors are available. 1/ In addition to these recommended paints, clear acrylic sealers do a very good job; e.g., HIAC Concrete Sealer, W. R. Meadows, Inc., 2 Kimball St., Elgin, IL 60120. However, these clear sealers are **not** recommended for **older** buildings, since existing stains will show through.

In almost all cases floor surfaces in vault toilet buildings slope towards the entrance door, and since there is usually no doorsill, water and detergent used in cleanup flows out the door. If the entryway is unsealed concrete, stains from the cleaning solution become an aesthetic problem. To prevent this, use a rough broom finish when finishing the outside concrete surface and then seal with clear acrylic.

When a vault toilet building is being designed, consideration must be given to future modifications. If there is any chance that the vault toilets will be converted to either oil-recirculating 2/ or minimum-water flush 3/ toilets, then perhaps the floor surface should slope to a middle outside drain. This will lessen problems if foreign material thrown into the flush toilets causes overflow 4/ and also makes floor cleaning significantly easier.

Interior Wall Surfaces

To prevent odor absorption and make cleanup as easy as possible, seal porous wall surfaces. Surfaces immediately adjacent to vault toilet risers should be coated or be of materials that are not easily carved

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1/ SDEDC Equip Tips, "Comfort Station Interior Finishes," August 1975.

2/ SDEDC Equip Tips, "Oil-recirculating Waterless Toilet," August 1975.

3/ SDEDC Equip Tips, "A Minimum-water Toilet Fixture," March 1973.

4/ Even though some oil-flush toilets have an overflow bypass to prevent oil spillages from a clog in the toilet throat, the bypass (or even the toilet-to-tank pipe) can become clogged and force oil onto the floor.

into to discourage those who are tempted to leave written messages. Materials such as high-density, overlaid plywood; sealed concrete block; ceramic tile; or dense, sealed hardboard are recommended.

Lighting

Adequate lighting is an important consideration in vault toilet building design. For daytime-only use areas, the use of translucent fiberglass roofing and ceiling panels can be effective. In overnight areas, since people avoid entering dark toilet buildings—especially women and small children, who are the most frequent users—perhaps lights (assuming available electricity) in conjunction with a timer are the best approach. These lights should be protected from vandalism by an enclosure. If placed in the building attic, install a translucent panel in the ceiling. In areas without electricity, consider the use of solar panel/battery-operated lights.

Toilet Paper Dispensers

The selection and installation of toilet paper dispensers should be based on projected number of users between scheduled servicing of the building and also expectations of vandalism. Any dispenser having easy-to-remove rolls will experience some losses to people wishing to start campfires or replenish recreational vehicle (RV) or household supplies. Dispensers are more frequently vandalized when empty.

Dispensers should be firmly fastened to the wall—preferably to studs or additional framing between studs. If the fastening screw heads are accessible, consider use of "one-way" heads. SDEDC recommends that local Forest Service units fabricate a three-roll, lock-bar dispenser (fig. 1)—design information is available from SDEDC. The bar is designed to prevent rotation of the rolls. The only way to completely remove a roll is to unroll it sheet by sheet, cut it off, or remove the lock. This type of dispenser allows the user to have all the paper desired but subtly discourages excessive use.

Figure 1. Three-roll, lock-bar toilet paper dispenser.

Vault Toilet Riser

A relatively new material (cross-linked polyethylene) is now being used to fabricate vault toilet risers by rotational molding (fig. 2). Some of the advantages of using cross-linked polyethylene are:

Figure 2. Vault toilet riser fabricated from cross-linked polyethylene.

1. Easy maintenance—smooth interior and exterior and there are no cracks or crevices.

2. Interchangeable with existing stainless steel risers.

3. Virtually no damage occurs when hit repeatedly with a heavy object, such as a sledge hammer but carving on the riser with a knife causes damage.

The riser can be obtained from Ontrak Designs, Inc., 21600 Osborne St., Canoga Park, Calif. 91304. Current price as of June 1978 is $41.50 with a standard seat

and $46.50 with a heavy-duty seat. The riser is offered in two colors—off-white and yellow (dirt will show on the off-white surface, if not cleaned regularly). Other colors are possible by contacting the manufacturer.[5/]

Building Interior Liner

A monolithic fiberglass building interior liner has been designed by Forest Service personnel in the Pacific Northwest Region (fig. 3). The advantages of using this liner as a toilet building interior are:

1. Easy maintenance—surfaces are smooth and there are no cracks or crevices.

2. Relatively low construction costs—liner for "standard" building compartment is $228 and for "handicap" one $325, as of June 1978.

3. Each liner comprises one stall—complete with an integral fiberglass toilet riser that is more aesthetic and easier to clean than the prevailing stainless steel risers. Also, since the riser has a standard commercial toilet seat it is more comfortable to use.

Figure 3. Monolithic fiberglass interior liner.

4. Carving the liner with a knife is difficult—marks made by abrasive implements can be spot repaired.

5. Liners damaged beyond repair can be removed and new ones installed—replacement should be considered during building design.

Information concerning the liners can be obtained from the Forest Service Regional Engineer, Pacific Northwest Region, P. O. Box 3623, Portland, Oregon 97208.

ODOR-CONTROL VAULT VENTING

Vault Toilet Odor Problem

Reports of bad odors in vault toilet buildings are the most frequent complaint that Forest Service recreation personnel hear. The obnoxious odors sometimes cause recreationists to avoid the toilet buildings and use the surrounding bushes. This can result in a health hazard as flies and rodents become potential disease carriers.

While no utopian answer to the odor problem exists, some measures can and should be taken. Use of innovative venting techniques can substantially reduce vault toilet odors during daylight (and possible early evening) hours, as shown in tests at SDEDC and user tests of redesigned toilet buildings in the California Region. These tests involved venting approaches not needing electrical power, since most vault toilet sites are without power.

Venting Techniques Tests

Most vault toilets presently in the field are vented with a 4-in (10.2 cm) round pipe placed in an interior corner of the building. SDEDC personnel conducted tests to determine if (1) large venting or (2) larger venting in conjunction with attic heating would facilitate odor removal and also (3) if turbine ventilators, or just extensions, placed over the vent outlets would improve air flow.

The idea behind a large vent in conjunction with

[5/] SDEDC Equip Tips, "Cross-linked Polyethylene Vault Toilet Riser," August 1978.

convection heating of attic air is that if a toilet building (fig. 4) is built with:

- An attic having a "large-enough" vent in the roof,
- A "large-enough" vent between the vault and the attic, and
- Properly located floor-level venting,

then a sufficient stream of fresh air will be drawn through the vent system to flush out foul odors that emanate from the vault.

The air will:

- Enter the building through the floor-level vents,
- Flow down the toilet risers and into the vault,
- Rise up the duct from the vault to the attic,
- Exit the attic through the roof vent, and
- Carry away the bad odors.

The air flow is initiated and maintained by convection, using the natural solar heating of the air in the toilet building's attic. Even on cloudy days, some radiant energy from the sun reaches the attic roof, and with larger ducts and vents than presently found in most toilet buildings, enough air will flow to eliminate odors in the building. By placing heat-absorbing material in the attic, warm air will remain for a time after sunset and keep the convection process going for a while longer. Unfortunately, this air flow technique of odor removal does not function on rainy days with little wind.

A typical two-unit toilet building with a 1,000-gal (3785 l) vault (fig. 4) was constructed and a 14- by 14-in (35.6 by 35.6 cm) exterior vent, with heavily insulated ducting to prevent warming of the vent by blowers and lamps used in the experiments, was installed on the outside. A hinged damper within the vent permitted air to travel either straight up and

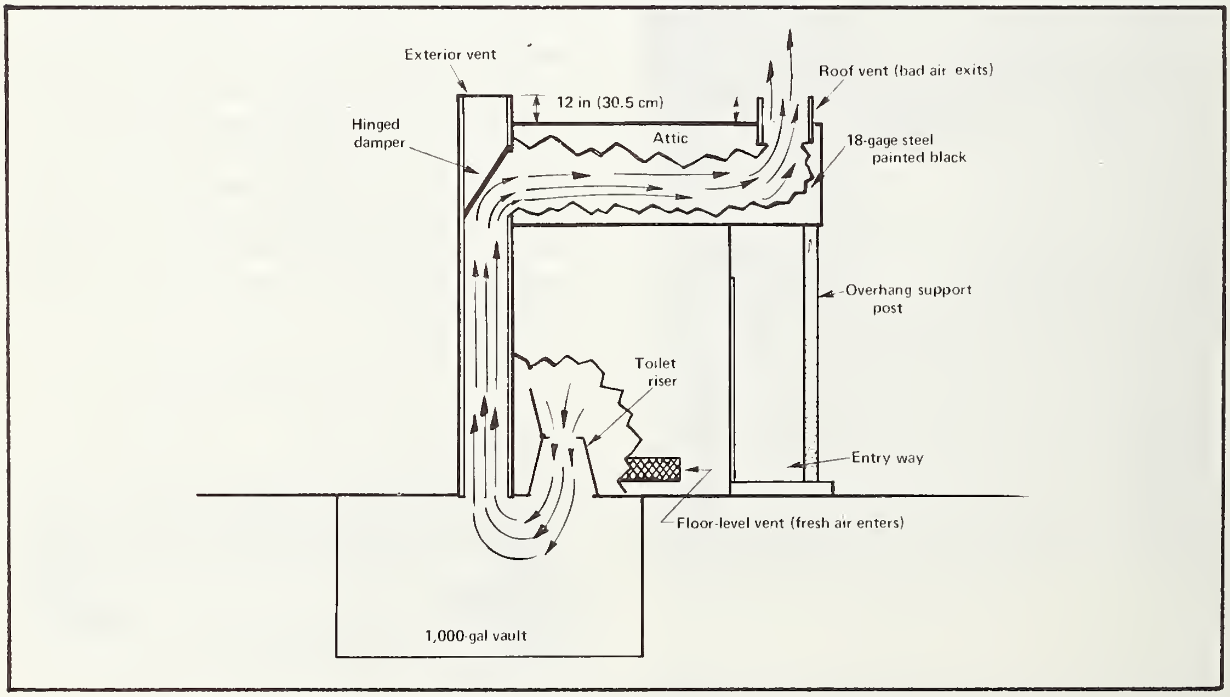

Figure 4. Attic venting test setup.

Table 1. Tests to optimize vault toilet venting systems

TEST CONDITIONS	MODIFICATIONS	RESULTS
1. Use various wind speeds and set hinged damper so air flows through exterior vent without going through attic.	a. Place 2-ft (0.61 m) extension over exterior vent.	a. Increased efficiency by a factor of 1½.
	b. Place 4-ft (1.22 m) extension over exterior vent.	b. Increased efficiency by a factor of 3.
	c. Place 16-in (40.6 cm) turbine ventilator over exterior vent.	c. Increased efficiency by not quite a factor of 1½.
	d. Insert 6-in (15.2 cm) round pipe the length of the exterior vent to simulate field installations.	d. Decreased efficiency by a factor of ¼.
2. Use various wind speeds and, with and without heat applied to roof, set hinged damper as in figure 3.	a. None	a. When wind speed < 5 mph (8.0 km/h), efficiency improved by heating attic; no difference in efficiency noted (heat or no heat) when wind 5 to 10 mph (8.0 to 16.1 km/h).
	b. Place 2-ft (0.61 m) extension over roof vent.	b. Same as "a" immediately above. Also, when wind speed >2 mph (3.2 km/h) and roof unheated, efficiency less when compared to 2-ft (0.61 m) extension on exterior vent, but not significantly.
	c. Place 16-in (40.6 cm) turbine ventilator over roof vent.	c. Slightly less efficient compared to placing 2-ft (0.61 m) extension, but not significantly.

out or detour through an attic and exit a roof vent having the same cross-sectional dimensions as the exterior ductwork. These dimensions were selected to match the area opening provided by the toilet risers in a two-unit toilet building.

The test building, which had an 18-gage steel roof that was painted black to absorb heat, was placed in the SDEDC indoor test bay that has air blowers and heat lamps. Using the adjustable venting system, various modifications were tested to determine which configuration produced the highest air flow; i.e., was the most efficient (table 1). In addition to the testing indicated in table 1, tests were conducted in a calibrated wind tunnel to compare 4-, 8-, 12-, and

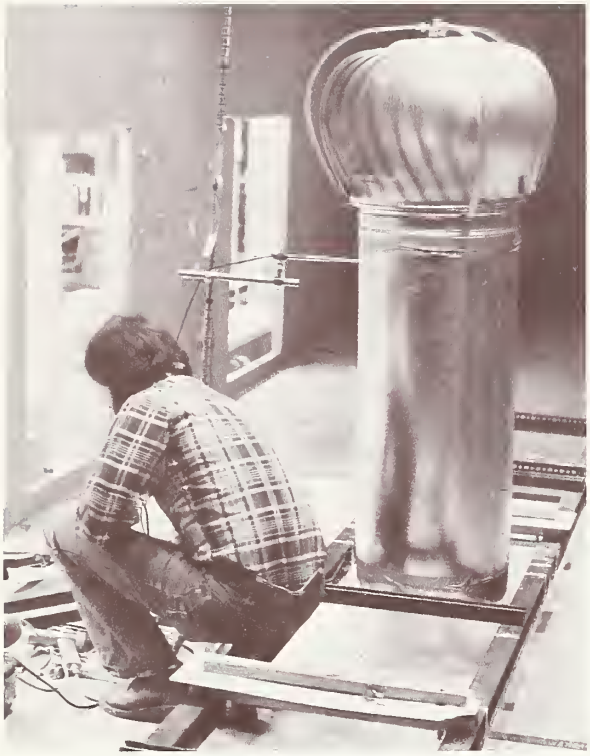

Figure 5. Turbine ventilator test setup.

16-in (10.2, 20.3, 30.5, and 40.6 cm) turbine ventilators (fig. 5) with open draw ducts of these same sizes, using wind speeds from 1 to 5 mph (1.6 to 8.0 km/h). Also, three-, four-, and five-bladed fans were attached to the 16-in (40.6 cm) turbine and were placed down into the duct to see if they would increase efficiency as the turbine caused them to rotate.

The wind tunnel tests showed that the 4-, 8-, and 16-in (10.2, 20.3, and 40.6 cm) open draw ducts averaged 18 percent more efficient than the turbine ventilators of the same three respective sizes. The 12-in (30.5 cm) turbine ventilator was, on the average, 13 percent more efficient than the same-size open draw duct. The three-, four-, and five-bladed fans attached to the 16-in (40.6 cm) turbine decreased the efficiency of the turbine by an average of 60 percent.

The 4-in (10.2 cm) vent system was capable of aspirating only approximately 30 cfm (14.2 l/s) at 5-mph (8.0 km/h) wind speed. On the other hand, the 16-in (40.6 cm) vent system aspirated between 300 and 400 cfm (141.6 and 188.8 l/s) at the same wind speed. Detailed wind tunnel data graphs are available, on request, from SDEDC.

In summary, the two test programs showed that the duct work, but not the small pipe, moved enough air to provide fresh air for toilet building users and, further, turbine ventilators (with or without attached fan blades) are not needed in a venting system.

Venting System Design Recommendations

To maximize the odor-removing ability of vault toilet building venting systems, both large-enough ductwork and an appropriate attic and roof should be provided. Based on the SDEDC test program, the following guidelines are recommended:

1. The vault-to-attic vent should have a cross section that is at least the cumulative area of the vault's toilet riser openings. In general, this means approximately 110 sq in (709.7 cm^2) for each riser leading into the vault.

2. The attic should have a roof vent with a somewhat larger cross-sectional opening from the vault-to-attic vent since the roof vent must have fly screening, which subtracts from the effective vent area.

3. The roof vent, which should not be connected to the vault-to-attic vent, should extend at least 1 ft (30.5 cm) above the highest ridge height.

4. Place a rain cap over the roof vent so that water will not accumulate in the attic. The rain cap should be constructed to allow for a 3- to 6-in (7.6 to 15.2 cm) gap between the top of the vent and the bottom of the rain cap (fig. 6).

5. Insulate the attic over the ceiling joists to prevent heat from permeating into the building's compartments. If translucent roofing is used, leave a panel in the ceiling uninsulated to allow sunlight into the building.

6. The roof over the attic should be designed and constructed so that the sun's rays will heat the attic. If a fiberglass translucent roof is used, place black building paper over the insulation covering the

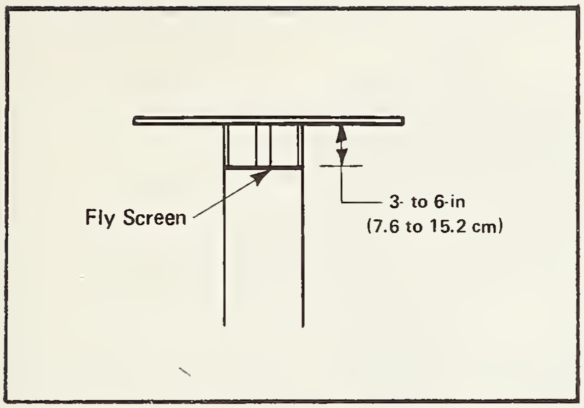

Figure 6. Flat-style rain cap over roof vent.

ceiling joists. A good nontranslucent material is metal painted a dark color. (While aesthetically attractive, a roof of ½-in (1.3 cm) plywood, black building paper, and cedar shingles or shakes insulates the attic from the sun.)

Interior Building Venting

A set of floor-level vent openings should be installed on two opposite sides of the building to provide air entry to disperse odors and evaporate both cleanup water and any misdirected urine. Be sure to cover all wall vents with fly screening. Unfortunately, floor-level venting can easily be damaged.

Vents fabricated from 12-gage expanded metal are effective, or—if concrete wall block or slumpstone is used for the building exterior—use decorative vent blocks (fig. 7). Additionally, a small vent at or near

Figure 7. Decorative concrete vent block.

the ceiling of at least one of the building walls can be effective in dissipating warm air that may accumulate above vault toilet risers.

Round vent pipe located in the interior corner of the building can easily harbor odor-emitting dirt in the inaccessible area between the pipe and the building corner (fig. 8). The odorous material accumulates in the inaccessible corner mostly during interior building spraydowns that occur during cleanups. The solution to this problem, as indicated in figure 8, is to encase the pipe from floor to ceiling.

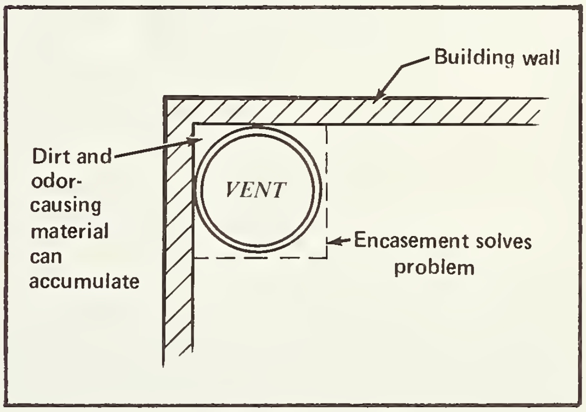

Figure 8. Round vent in square corner.

Venting Improvements for Existing Buildings

All existing designs could not possibly be commented on here, so only a few typical designs have been addressed. Many present-day vault toilet building venting systems contribute little to odor removal. Figure 9 exhibits features that result in an ineffectively vented building. Here wall vents are of a size and placement that were intended to provide ventilation and light into the compartments. Unfortunately while side 1 (windward compartment) is odor-free, side 2 can have an odor-saturated airstream and be unbearable.

To effect odor removal, install a partition in the vault between sides 1 and 2 and put in floor level vents (fig. 10). Also increase the vent stack size in both compartments to approximately 220 sq in (1419.4 cm^2). Terminate these stacks in the attic, which should be insulated, and reroof with a heat-absorbent material. Finally, construct a vent out of the roof that is at least 1 ft above the highest ridge

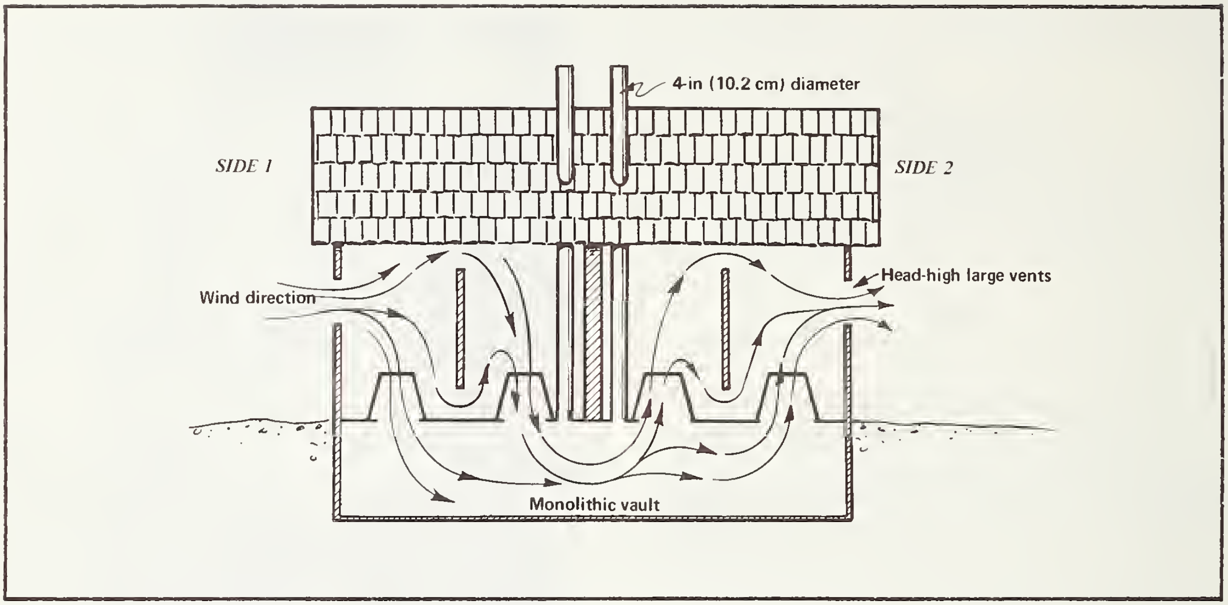

Figure 9. Poor multi-hole venting design concentrates bad odors.

height. Do not connect this roof vent to the two vents from the partitioned vault. The roof vent should be a little larger than the combined area of both vault-to-attic vents, since it should be topped-off with fly screening and a rain cap.

Some current building designs include a partitioned vault for noise suppression between side 1 and side 2; this partition has no effect on odor reduction (fig. 11). The air flow through side 1 and side 2 is similar to that shown in figure 9. Corrective action that can improve this design includes placing smaller side vents—only one per compartment—under the eaves of the roof, enclosing the existing side vents with non-breakable translucent material (such as Plexiglass), installing another partition in each vault between the existing side vent openings (make four individual vaults), and venting each compartment with floor-level vents on two sides. The vault-to-attic vent for each of the four vaults should be sized according to

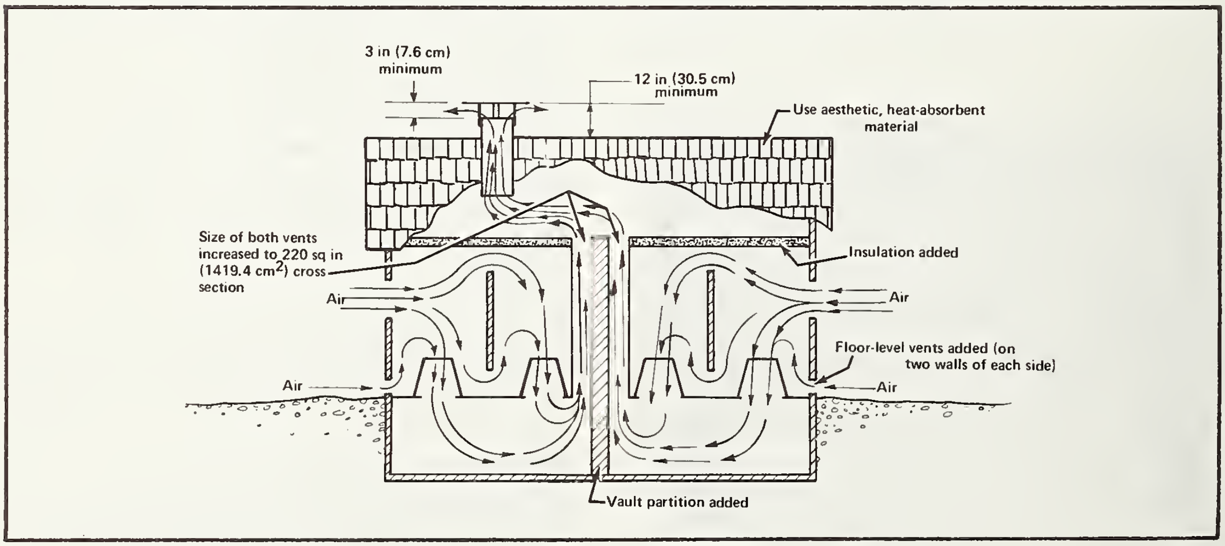

Figure 10. Good multi-hole venting design minimizes bad odors.

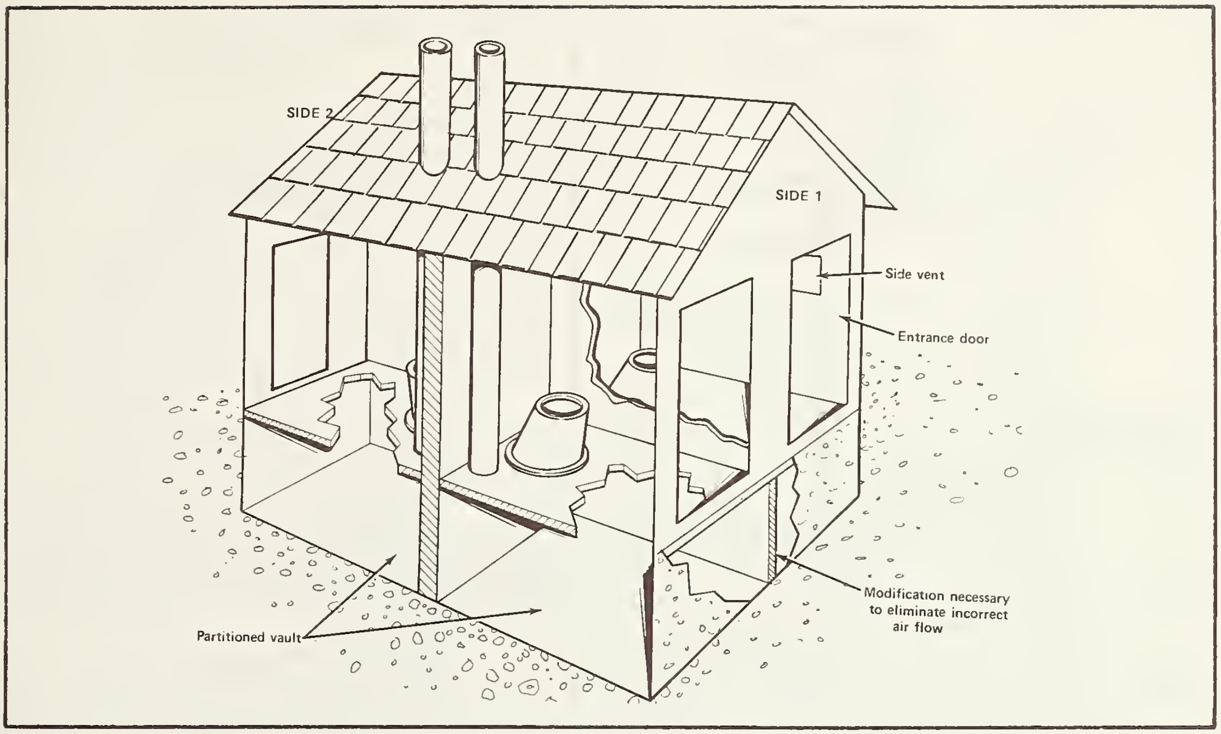

Figure 11. Another poor multi-hole venting approach.

item 1 under "Venting System Design Recommendations." The roof and roof vent should be constructed as shown in figure 10.

Again, the roof vent should be a little larger than the combined area of all four vault-to-attic vents and should be screened for flies and have a rain cap.

Single-hole toilets in small buildings present a particular odor-removal venting problem (fig. 12). The air flow through the building is sometimes greater than the effect of the typical 4-in (10.2 cm) vault-through-roof vent, so odors are drawn into the building compartment from the vault by the venturi action of the air going through the building. This design can be modified (fig. 13) by closing the side vents with nonbreakable translucent material and increasing the vault-to-attic vent cross-sectional size—along with the previously indicated attic modifications that produce a heat chamber. Smaller side vents could be installed near the ceiling to allow better air circulation by providing an exit for any air in the building that is warmed by the sun.

Single- or double-unit toilets, having a fiberglass roof to let in sunlight, but not having an attic, provide a

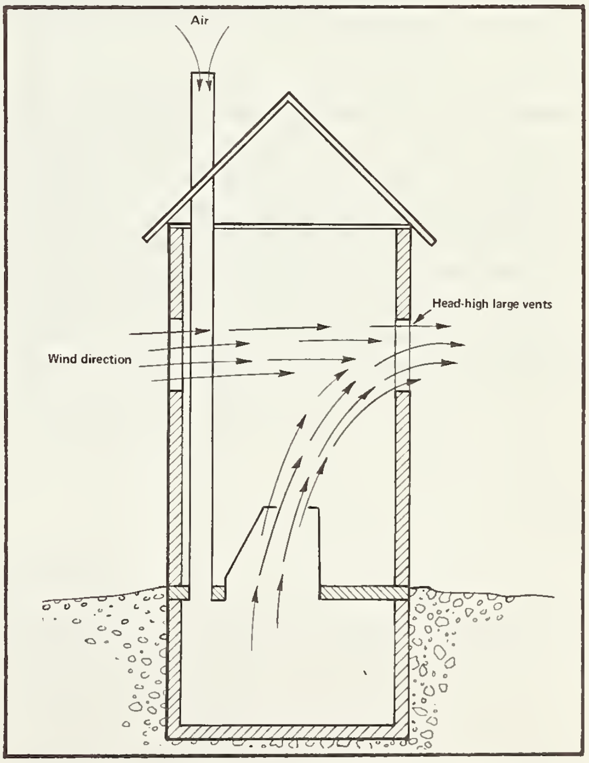

Figure 12. Poor single-hole venting design concentrates bad odors.

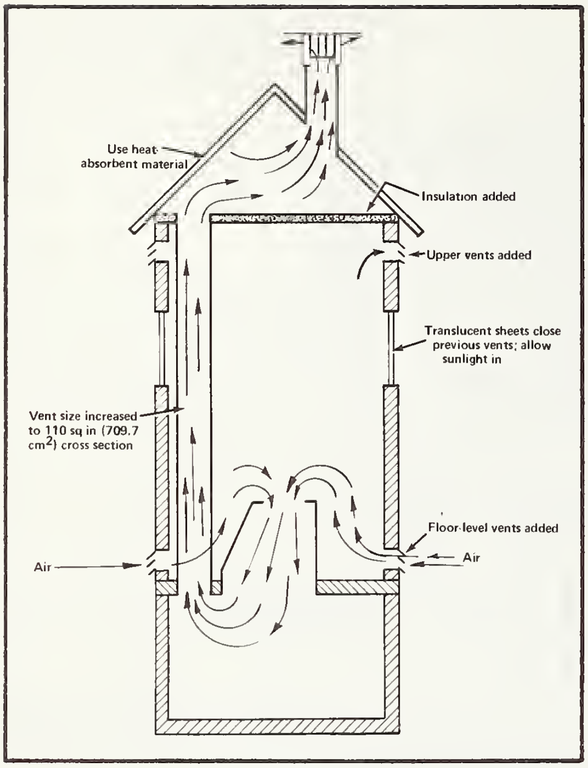

Figure 13. Good single-hole venting design minimizes bad odors.

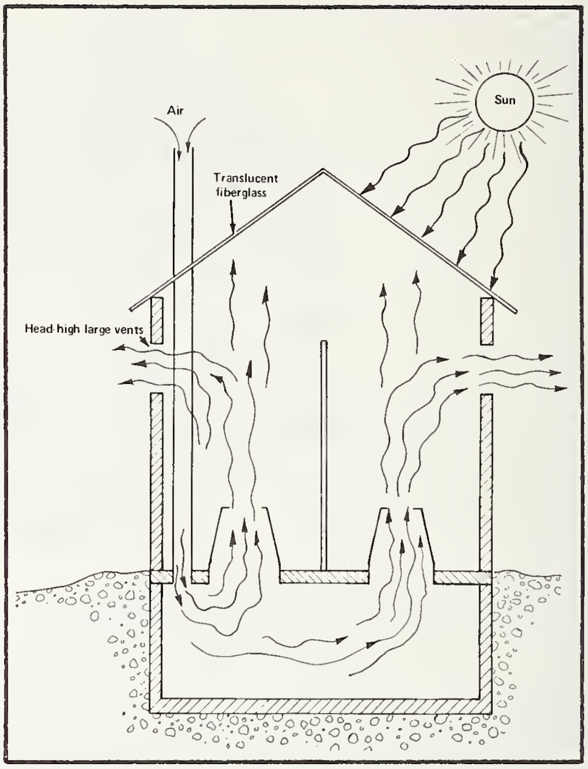

Figure 14. Poor roof design concentrates odors.

natural convection process that causes odors to be drawn up from the vault (fig. 14). The sun shining through the translucent roof heats up the building interior and the warm air rises and exists through the side vents. This convection process draws foul air up from the vault, resulting in a flow of outside air down through the small vent into the vault, up through the toilet riser, and into the building. The cure for this (see fig. 15) is to build an attic into the building, insulate at the joists, and place black building paper on the insulation. A small translucent panel can be placed within the ceiling to provide light into the building's compartments.

Also, appropriately increase the size of the vault-to-attic vent, terminate this vent inside the attic, place another appropriately sized vent, with screening, out of the roof, and install floor-level vents. The side vents should be replaced with translucent material. If the side vents are closed with the translucent material, then add small upper vents near the building's ceiling.

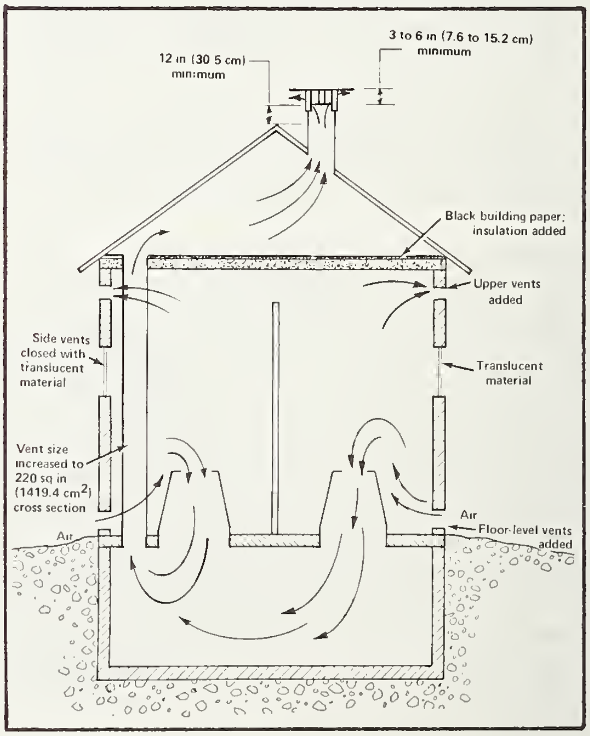

Figure 15. Good roof design minimizes odors.

ODOR-CONTROL CHEMICAL AND BIOLOGICAL ADDITIVES

The foul odors emanating from human waste result primarily from bacterial action within the waste. Anaerobic bacteria (those that do not use oxygen) dominate in the vault mass and produce odors of sulphides (rotten eggs), organic amines (sour), and most of the other unpleasant smells. Aerobic bacteria (those that consume oxygen) prevail on the vault walls and other air-exposed surfaces, such as urinals and floors, and produce ammonia odors.

The Forest Service purchases many different chemical and biological additives for vault toilet odor reduction, cleanup, and waste mass decomposition. While coverage of all aspects of these additives is beyond the scope of this report, the practicality and some detrimental effects of additive use are explored.

Chemical Additives

Chemical Action

Effective chemical odor control generally utilizes a combination of methods. Chemical additives can:

- Inhibit bacterial growth,
- "Complex" (chemically change) the odor-producing components, and
- Mask, or cover up, bad odors with a more pleasing scent.

Chemicals added to the vault may influence waste disposal practice. Waste treatment plants are biological factories in which bacteria accelerate waste conversion. These bacteria are acclimatized to certain concentrations of nutrients peculiar to each waste facility. The treatment plant operator is properly cautious about upsetting his bacterial factory and wants to know beforehand what will be the effect of the chemicals in the vault waste.

Chemical additives may function to eliminate the dominant bacteria, dissolve grease, or clean surfaces. Chemicals offered primarily for odor control fall into the following broad categories by composition, and may be offered singularly, or in combination, by various manufacturers:

- Phenols
- Chlorinated hydorcarbons and dichlorobenzene
- Formaldehyde
- Quartarnary ammonia compounds
- Heavy metal compounds.

Table 2 presents details on how these chemicals function and their influence on waste disposal.

Corrosive Effects

The corrosive nature of chemical additives should always be considered as they relate to vaults constructed of concrete, concrete block, fiberglass, steel, synthetic rubber, and cross-linked polyethylene. Phenols have a high pH (between 10 and 12). Alkaline mixtures will adversely affect the polyester resin most commonly used in fiberglass. Isophthalic resins offer some alkali resistance, but are not commonly used and are more expensive. Dichlorobenzenes are a solvent for polyester resins and may also be harmful to some synthetic rubber products (like Butyl and Hypalon).

Concrete is severely attacked by a high pH (9+), because the alkali combines with the calcium hydroxide and expands, causing what looks like freeze/thaw spalling. However, penetration continues. Type 5 cement, having less tricalcium aluminate (cementing agent), is used to help prevent alkali attack. Existing vaults using normal cement do not have this protection and are subject to severe attack.

Formaldehyde, when used as directed, has little or no effect on any of the presently used vault construction materials.

Cross-linked polyethylene is not affected by any of the chemical additives now on the market.

Biological Additives

Biological additives are generally grouped as either

bacteria or enzymes. Bacteria reproduce themselves; enzymes do not. Enzymes in biochemical reactions act as organic catalysts. The enzymes actually become part of the action but, having caused it, split-off from it and are themselves unchanged. Bacteria are dependent on pH and can only function within a small temperature range. Colonies of bacteria are literally factories for the production of enzymes. The enzymes produced by the bacteria are appropriate to the substrate in which the enzyme is working, so there is an automatic infinite production of the right enzyme for biological activity within any waste material, providing you have the right bacteria to start with.

Table 2. Chemical additives

AVAILABILITY	REMARKS
Phenols	
a. Includes phenol, creosol, "sheep dip," and chlorinated phenols and their alkali salts (e.g., sodium phenates).	a. Do **NOT** use! True, at very low concentrations (0.5 to 5 mg/l phenol), excellent odor control is obtained. However, these low concentrations upset waste treatment plants by killing the bacteria. Most treatment facilities will **NOT** accept waste stabilized with bacteriostats like phenol or phenolic compounds.
b. Many household cleaners (Lysol, etc.) use phenolic compounds.	b. While these household products may be used to clean interior building compartments; use them **sparingly,** since they will accumulate in the vault.
Chlorinated Hydrocarbons and Dichlorobenzene	
a. Liquids for septic tank cleaning.	a. Effective grease solvent for opening clogged septic tank and leach field lines. Also dissolves grease and fats on vault walls. Only odor control provided is a slight masking effect. Most treatment plants will accept waste stabilized with these liquids.
b. Solid "parablocs."	b. These are dichlorobenzene pressed into solid cakes laced with perfume. The cake evaporates, producing a heavier-than-air gas blanket over the waste. The perfumes are lighter and rise to mask foul odors. The blocs have some effectiveness in urinals and other ventilated areas.
Formaldehyde	
a. Liquid solutions of formalin (37.5 percent formaldehyde).	a. Formaldehyde, commonly used as a space fumigant, is a gas that evaporates very rapidly from solution. Its solutions are effective odor suppressants because they (1) are bacteriorstats that depress bacterial growth, (2) chemically complex odor-causing compounds, and (3) mask foul odors since formalin deactivates nasal tissues.

Table 2. Chemical additives (continued)

b. Proprietary formaldehyde deodorant preparations.	b. These are less concentrated than formalin and contain perfumes. Manufacturers may complex the formaldehyde in solution so that an effective 18 percent formaldehyde solution is less disturbing than 5 percent formalin. When properly diluted, formaldehyde compounds are biodegradable. If used according to the manufacturers' directions, most of the formaldehyde will react with the bio-organics (human waste) and will, therefore, be unavailable as an antiseptic when dumped into any sewage treatment system.
c. All formaldehyde formulations.	c. By successive transfer of micro-organisms into increasingly higher concentrations of formaldehyde, the micro-organisms adapt to significantly higher concentrations of formaldehyde than normally considered inhibitory to microbial growth. Therefore, once the micro-organisms in a sewage treatment system became adapted to the presence of formaldehyde, relatively high levels of this chemical can be added to the system without untoward effect.
Quaternary Ammonium Compounds	
Brand name products	"Quats" are recognized by health departments as effective disinfectants for restaurants. They are also marketed as RV toilet deodorants. The various quats may be used to wash down interior toilet building walls and floors. They are good cleaning agents, and will leave a residue with a long-term effect. Quats are biodegradable and will not disturb treatment plants. However, quats are not effective in extremely hard water, where calcium and magnesium are present and, unfortunately, vault liquid waste contains much dissolved calcium and magnesium.
Heavy Metal Compounds	
Zinc sulfate is still occasionally offered, primarily for RV toilets	Zinc sulfate, a heavy metal salt, is a bacteriostat that cannot be removed by conventional waste treatment processes. It is toxic to many fresh water fishlings and must **NOT** be discharged in quantitites that exceed stringent Federal and State guidelines. Thus, zinc and other heavy metal compounds (such as chromium and mercury) should absolutely **NOT** be used!

Manufacturers' claims indicate that adding these bacteria or enzymes to vaults will eliminate odors and reduce the mass that has to be pumped. During an 85-day test conducted at SDEDC, vault fecal matter was subjected to a liquid bacteria and a dry-powder enzyme under controlled conditions and in cooperation with the manufacturers of each product. There was no reduction of odor and, according to laboratory tests, there was no reduction of fecal matter.

Practical Aspects of Additive Use

The quantity and frequency of additive use is a critical consideration, especially with respect to biological products. The makeup of the waste mass affects the ability of an additive to function as intended. Also, debris floating on the vault waste surface can prevent an additive from mixing with vault contents. Further, Recreation personnel are reluctant to stir vault contents because the immediate result of this action is the rise of significantly magnified odors. A chemical or biological agent (alone or in combination with vault contents) can cause an objectionable odor having nothing to do with normal vault waste odors.

When considering additives, don't be concerned with claims that an additive can "liquify the waste mass to make pumping easier." Fecal matter and toilet paper do not cause pumping problems. See appendix III for a list of items that do cause pumping problems and note that liquification products would be of little use in dissolving these.

Questions on the two types of additives that need to be answered when considering their use in vault toilets are presented in table 3.

BELOW-GROUND VAULT CONSTRUCTION

Many materials are being used to construct toilet vaults—including concrete, concrete block, fiberglass, steel, synthetic rubber, and cross-linked polyethylene. Many of these materials are not practical and really should not be used. An important design consideration in high water table areas is the uplift pressures and their effect on the vault. Some advantages and

Table 3. What to consider before ordering vault toilet chemical and biological additives

CHEMICAL PRODUCTS

1. Will waste containing the chemical be accepted by local treatment processors or be harmful to the environment if discharged into a sanitary landfill?
2. Will the chemical (alone or in combination with vault contents) deteriorate the quality of the vault?
3. Will Recreation personnel be able to handle the chemical safely?

BIOLOGICAL PRODUCTS

1. Will the vault contents' pH and temperature be conducive to desired biological activity?
2. Will the biological additive be effective if chemically laden toilet waste from RV's or detergents from recreationists' clothes- and dish-washing efforts are dumped into the vault?

BOTH CHEMICAL AND BIOLOGICAL

1. Will the shelf life of the product be adequate?
2. Will a leaking vault deprive the products of enough water to function in?

disadvantages of each material are presented in the paragraphs that follow.

Concrete

Advantage

Concrete is readily available.

Disadvantages

Concrete is heavy and difficult to handle. If the tanks are not properly designed and constructed, the concrete can crack or be very porous, absorbing difficult-to-eliminate odors. Furthermore, coatings applied to concrete can crack when the concrete cracks, and certain epoxy paints and bituminous coatings are removed by chemical and biological reaction with sewage. Also, concrete, which is usually light in color, reflects available light, making the waste mass visually unpleasant.

The in-place pouring of concrete prolongs building time because of the forming and the normal 7-day or high-early cement curing time. In addition, poured-in-place concrete requires special skills and is expensive; for a 1,000-gal (3785 l) vault, the cost is \$1,500 to \$2,000. Type 5 (sulfate-resistant) Portland cement should be used, since the waste mass in the vault generates hydrogen sulfide gases that attack the cementing agent (tricalcium aluminate) and alkali that attack cement's main hydration product (calcium hydroxide). These attacks can result in poor structural integrity, causing collapse of the vault.

Concrete Block

Concrete block should never be used to contain sewage, as it is highly porous and obtaining a water-tight seal is very difficult, requiring special coatings.

Fiberglass

Advantages

Fiberglass is readily available and weighs less than concrete or steel.

Disadvantages

Fiberglass is brittle, easily damaged in transport and installation, and subject to temperature-differential cracking. It is, generally, the most expensive of all the materials. Recently various types of fiberglass tanks have collapsed after installation. The design of all fiberglass tanks should be carefully examined for strength and alkali-resistant formulation.

Most commonly used polyester resins in fiberglass are not isopthalic, and are subject to alkali attack, either from the soil or the sewage. Products containing chlorobenzenes or phenols (high pH) will attack the polyester resins in fiberglass. Also, the configuration of most fiberglass vaults provides poor access, making them difficult to clean. Concrete should be poured into the bottom of any fiberglass vault to prevent damage from miscellaneous debris, like rocks, thrown into the vault or the metal end of a commercial pumper's suction hose.

Steel

Advantage

Steel is durable and, if corrosion protection remains intact, will last a long time.

Disadvantages

Steel is heavy, difficult to handle, and corrodes easily if not properly coated. Thus, careful installation to protect the steel's coating is critical; however, debris thrown into the vault can easily chip most coatings placed on steel, allowing corrosion to begin.

Steel tanks are expensive and are not always readily available. If corrugated pipe is used, the interior is hard to clean and the pipe is usually not large enough to provide outside access for pumping.

Synthetic Rubber

In an effort to locate a suitable material to prevent in- and ex-filtration in existing vaults, Neoprene, Butyl, chlorinated polyethylene, polyvinyl chloride, polyethylene, Nordel, vinyl, Hytrell, and Hypalon were considered. Taking into account economics, durability, quality control, installation, chemical resis-

tance, availability, and repairability; 45-mil, black nylon-reinforced Hypalon is recommended by a rubber industry spokesman as the most suitable material for use in existing vaults; it also can be used in new vault construction.

Advantages

The liner can be placed into an existing vault through either the toilet riser hole or the manhole. The fact that it stands vertical in the vault is no problem; it will not sag since it is nylon-reinforced. The liner is manufactured with evenly spaced metal grommets in the top overlap of the material, allowing easy attachment to concrete (or concrete block) with lead or plastic inserts and screws going through 1- by 3-in (2.54 by 7.62 cm) redwood or cedar boards.

If the Hypalon is torn or punctured during installation, it can easily be repaired. For new vault construction, any size or configuration is possible, as the liner is not assembled until the manufacturer receives the exact dimensions. The liner is fully assembled at the factory, requiring no field seaming, and is available throughout the country.

Hypalon's physical properties (see appendix I) make it a very good choice for vault toilets. To reduce light reflection, and thus the visual impact of the waste mass, specify a black liner.

Disadvantages

Concrete must be poured into the liner to a depth of 3 or 4 in (7.6 to 10.2 cm) to prevent puncture from miscellaneous debris thrown into the vault (see appendix III). The concrete poured into the liner to protect the bottom may not be sufficient to prevent uplift due to water infiltration through the original concrete or concrete block vault. The sidewalls of the Hypalon can become punctured from sharp implements used by a pumper operator to remove miscellaneous debris.

The liner should be tested for leakage before it is installed into a vault.

Cross-linked Polyethylene

Considering economics, durability, installation, cleaning ease, nonabsorption of odors, chemical resistance, weight, and longevity, cross-linked polyethylene appears to be a very practical material for new vaults. (See appendix II for its physical properties.)

Advantages

The holes for the toilet risers, vents, and the cleanout manhole can be easily cut with a sabre saw at the construction site to match many toilet building designs. Since the material is monolithic, scratching of its surface by rocks or other debris thrown into the vault, or by pumping operations, will not affect the quality of the tank. The smooth interior walls help to prevent fecal matter from sticking to the surface, and the material is nonporous, so odors cannot be absorbed. Below zero temperatures (to -20^{o} C; -4^{o} F) have little effect on the structural integrity of the material, and its resistance to chemicals exceeds that of all other materials tested for vault use.

Disadvantages

Production of cross-linked polyethylene is limited presently to plants in California. The rotation molding process requires large, specialized equipment and certain fabrication expertise. At present, molds exist to produce a 500-gal (1892.5 l) rigid liner and a 1,000-gal (3785 l) self-supporting vault. The mold for the latter cost $6,000; fabrication of additional sizes would incur a large capital expense. Finally, since the tanks have a high displacement-to-weight ratio, uplift forces of high water tables are a design consideration.

FUTURE WORK

The concepts for improving building interior design, toilet paper dispensing, approaches to venting, etc., documented in this report resulted from attempts to solve problems reported by Forest Service managers and Forest users. Where these concepts have been adopted or incorporated they have proven beneficial. By incorporating the many suggestions presented in this report and continuing to exchange information on the successes achieved and problems encountered, the state-of-the-art for vault toilets can be further advanced.

The Environmental Staff Engineer at San Dimas will continue to review field experience with the new concepts. Please do not hesitate to contact SDEDC about your successes, failures, and problems—and most especially with your ideas and suggestions.

APPENDIX I–PROPERTIES OF SYNTHETIC RUBBER (Hypalon ®)

The physical properties of E. I. duPont de Nemours & Co.'s Hypalon, as supplied by duPont, are given in table I-1.

Table I-1.—Physical properties of Hypalon

PROPERTY	TEST METHOD	DATA NYLON SCRIM	POLYESTER SCRIM
Weight	–	0.332 lb/sq ft (1.62 kg/m^2)	0.332 lb/sq ft (1.62 kg/m^2)
Thickness (min)	–	0.041 in (1.0 mm)	0.041 in (1.0 mm)
Puncture resistance (min)	FTMS 101B, method 2031	180 lb (81.6 kg)	180 lb (81.6 kg)
Breaking strength (min)	ASTM D751, grab method		
	• Fabric	100 lb (45.4 kg)	100 lb (45.4 kg)
	• Rubber	150 lb (68.0 kg)	150 lb (68.0 kg)
Elongation (min)	ASTM D751,		
	• Fabric	20%	15%
	• Rubber	150%	150%
Tear strength (min)	ASTM D751, tongue tear	20 lb (9.1 kg)	20 lb (9.1 kg)
Ozone resistance	ASTM D1149 50 pphm 20% strain, 100° F, 8,000 hr	No effect	No effect
		Low Temperature Resistance	
Cold bend test	ASTM D2136, 1/8 in mandrel	-45° F (-43° C) (no crack)	-45° F (-43° C) (no crack)
Brittleness point	ASTM D746, procedure B	-45° F (-43° C)	-45° F (-43° C)
Factory and field seam strength	ASTM D816, method C	Exceeds that of parent material	

Hypalon synthetic rubber liquid-containment liners (black, 45-mil, five-ply) can be ordered from the following firms:

CALIFORNIA

Burke Rubber Co., Inc.
2250 South Tenth Street
San Jose, CA 95112
408/297-3500

MICHIGAN

St. Clair Rubber Co.
Marysville, MI 48040
313/364-7424

KANSAS

Gaston Containment Systems
P. O. Box 1157
El Dorado, KS 67042
316/321-5140

OHIO

B. F. Goodrich
500 South Main Street
Akron, OH 44318
216/379-2827

APPENDIX II–PROPERTIES OF CROSS-LINKED POLYETHYLENE (Marlex CL-100)

The basic ingredient of cross-linked polyethylene is Phillips Petroleum's Marlex CL-100. Table II-1 presents the nominal physical properties of this material, based on molding at 650° F (343° C) for 13 min. All data in the table were supplied by Phillips Petroleum Co.

Table II-1.–Physical properties of Marlex CL-100

PROPERTY	ASTM TEST	DATA
Cross-linked density	D1505-68	0.930-0.933 gm/cc
Environmental stress cracking resistance, condition A, F_{50}	D1693-70	>1,000 hr
Tensile strength, 2 in/min, ultimate	D638-72, Type IV specimen	2,600 psi (17 926 kPa)
Elongation, 2 in/min, at break	D638-72, Type IV specimen	450%
Vicat softening temperature	D1525-70	~240° F (~115° C)
Brittleness temperature	D746-73	<-180° F (<-118° C)
Flexural modulus	D790-71	100,000 psi (689 470 kPa)

DROP IMPACT OF A MOLDED CONTAINER

Cycle time at 600° F (315° C)		14 min
Drop height [1]	73° F (22.8° C)	>30 ft (>9.1 m)
	-20° F (-28.9° C)	>30 ft (>9.1 m)

[1] Two-gallon container, weighing 800 gm, filled with water.

Cross-linked polyethylene vault toilet risers and 1,000-gal (3785 l) vaults can be ordered from Ontrak Designs, Inc., 21600 Osborne St., Canoga Park, CA 91304; phone 213/998-5105. Cross-linked polyethylene 500-gal (1892.5 l) rigid liners for vault toilets can be purchased from Hollowform, Inc., 6345 Variel Ave., Woodland Hills, CA 91364; phone 213/884-0949.

Managers of recreation sites often do not realize why vault toilet pumping contracts cost so much, nor do they understand why stipulations in these contracts are so difficult to administer. The answer to these questions lies in the diversity of the waste contents that can be found in vault toilets. To gain an insight into exactly what a typical vault contains, a men's two-seat vault toilet on the Angeles National Forest was inventoried. According to the records, this vault had not been pumped in 3 yr. First, much of the miscellaneous non-liquid material was removed and then the vault was pumped. To get a complete debris inventory, the pumped contents were screened over a manhole to capture items not removed before pumping began. Thus, the inventory is reported in two lists–debris removed before pumping and contents screened from the pumped waste mass (tables III-1 and -2).

Another men's two-seat vault toilet on the Angeles National Forest was pumped out by a contractor, assisted by Forest Service employees, who helped remove some solid debris on top of the waste mass and used a Model 60 fire pumper to pump 700 gal (2649.5 l) of water at 300 psi (2068.4 kPa) to aid in breaking up the sewage mass.

The contractor hauled off five 30-gal (113.6 l) plastic bags containing the surface solid debris. Also, approximately 500 gal (1892.5 l) of liquid waste plus the 700 gal (2649.5 l) of added water was pumped out. This lowered the contents of the vault by only 3½ ft (106.7 cm). A few days later SDEDC personnel inventoried (table III-3) the solids that remained in the vault.

Table III-1. Debris removed, before pumping, from a men's two-seat vault toilet.

QUANTITY	ITEM	QUANTITY	ITEM
68	Cans	1	Apple
59	Plastic bags, approx. 3½-gal (13.2 l) capacity	1	Strip of rubber, 1- by 20-in (2.54 by 50.8 cm)
26	Full rolls of toilet paper (plus a partial roll)	1	Large rag
21	Styrofoam cups	1	Section of cardboard box
11	Bottles	1	Tube of antiseptic, ¾ full
8	Empty plastic wrappers—bread, rolls, potato chips, paper napkins, etc.	1	Small cardboard donut container
7	Sticks, 1 to 4-ft (30.5 to 121.9 cm) in length	1	Toilet paper holder, in good condition
6	Ponderosa pine cones	1	Full 12-oz (0.35 l) Pepsi can
4	Wads of aluminum foil	1	Large plastic bowl
4	Men's "boxer" shorts	1	Sanitary napkin
3	Plastic cups	1	Contraceptive
3	Small rags	1	Plastic fork
3	Men's "Jockey" shorts	1	Paper bag
3	Boy's "Jockey" shorts	1	Long piece of string
2	Elastic bands from "Jockey" shorts	1	Paper towel
2	Boy Scout caps	1	Plastic straw
2	Wires, 4-ft (121.9 cm) long	1	Cap from spray can
2	Bent wires, 2-ft (61.0 cm) long	1	Plastic camera strap, 2½-ft (76.2 cm) long
1	Cloth dinner napkin	1	Hypodermic syringe
1	T-shirt	1	Large piece of plastic toy, 4- by 10-in (10.2 by 25.4 cm)
1	Large bag of 8 diapers	1	Wire container for solid deodorant
		1	Cu yd rock (left in the vault)

Table III-2.—600-gal (2271 l) of material screened from the same men's two-seat vault toilet.

QUANTITY	ITEM	QUANTITY	ITEM
28	Paper towels	1	Orange
10	Plastic bags, approx. 1-gal (3.8 l) capacity	1	Rope, 18-in (45.7 cm) long
		1	Small piece of wood
8	Aluminum can pull tabs	1	Large weed
7	Wads of aluminum foil	1	Small wiener package
3	Wads of bubblegum	1	Contraceptive
3	"Jockey" shorts	1	Flash bulb
3	Ice cream bar sticks	1	Wine bottle cork
2	Combs	1	Styrofoam cup
2	Plastic caps	1	Small plastic tube
2	Rags	1	Chicken bone
2	10-qt (9.46 l) buckets of paper plus numerous cigarette packs and gum wrappers; also lots of small rocks	1	Mitten, wool
		1	½-pt (0.24 l) drink container
1	Whittling stick	1	Plastic spoon
1	Name plate from toilet stool (Monogram)	1	Peach pit
1	Squirrel-eated pine cone	1	Copenhagen snuff cap

Table III-3.—Debris removed from another men's two-seat vault toilet after a contractor finished pumping

QUANTITY	ITEM
395	"Small" rocks
125	Beverage cans
55	Plastic bags, approx. 3½-gal (13.2 l) capacity
18	Sticks
15	Full rolls of toilet paper
12	Pine cones
11	Large rocks (2-10 lb; 4-15 lb; 1-20 lb; 2-30 lb; 1-50 lb; 1-75 lb) or (2-4.5 kg; 4-6.8 kg; 1-9.0 kg; 2-13.6 kg; 1-22.7 kg; 1-34.0 kg)
11	Bottles (2 broken)
10	Large food cans
8	Rags
8	Cups (4 styrofoam, 3 plastic, 1 paper)
3	Plastic juice containers
3	"Medium"-size pieces of aluminum foil
3	Styrofoam butcher-shop meat trays
2	Plastic margerine tubs
2	Toilet paper holders
2	Blocks of wood
2	Undershorts
2	Metal spoons
2	Plastic forks
2	Aluminum pie pans
2	Tin can lids
2	Wooden stakes
1	Sardine can with lid
1	Half a bucket of gravel
1	Large stack of cardboard
1	Paint can
1	Paint can lid
1	Rope
1	Wooden handle, 14-in (35.6 cm) long
1	D-cell battery
1	Comb
1	Ham can
1	Stainless-steel rod, 6-in (15.2 cm) long, threaded
1	Plastic ice container
1	Handle from fire extinguisher
1	Toilet seat cover (broken)
1	Wire container for solid deodorant
1	Plastic lid
1	Rubber band
1	"Handywipe"
1	Plastic quart bottle
1	Coat hanger
1	Jar lid

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